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RADIOLOGICAL SAFETY ASPECTS OF THE

NUCLEAR POWER PROGRAM

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RADIATION SAFETY ASPECTS OF NUCLEAR POWER PROGRAMS

INTRODUCTION

The use of nuclear power to generate electricity has led to the development of new technology. No other program in human history has been undertaken with the total commitment to safety as found in the nuclear power program. This commitment to safety both for plant operating personnel, for the general public and for man's environment has proven effective. Experience has demonstrated that present technology is adequate to maintain radiation doses in the vicinity of nuclear power plants--on the average--to small percentages of background radiation.

The nuclear power industry is expanding rapidly. Construction and startup of nuclear power reactors is proceeding at a fast pace, with the number of operating power reactors in the United States expected to increase from 21 as of March 1971 to about 90 by the end of 1975. Since these facilities cannot operate without discharging exceedingly small but measurable quantities of radioactive wastes into the atmosphere and hydrosphere, and since no 100% absolute assurance can be given that significant inadvertent releases will never occur, segments of the public have become increasingly concerned about the radiological safety aspects of nuclear facilities.

Nuclear power reactor operators are required by the USAEC, as a condition to their license, to monitor effluents from their plants for radioactivity and to control such releases to standards set in the interests of public health and safety. In some instances, State health agencies separately survey individual facilities for environmental radioactivity levels. The USAEC also obtains independent information on radioactivity discharges and environmental radioactivity levels through its own offsite surveillance programs. In the vast majority of instances, changes in the human radiological environment are not observable in the "noise level" of natural background radiation.

DESIGN FEATURES

Nuclear power Plants have many advantages when compared to fossil fueled power plants with respect to the environmental contaminants, but the fission process inevitably creates radioactive products with a wide variety of chemical and radioactive properties. The longer a nuclear facility operates on a given fuel loading, the larger the inventory of fission products becomes. Thus, when a nuclear power plant first begins operation, the only radioactive materials present are the naturally radioactive isotopes comprising the nuclear fuel. After initial operation, some of this fuel inventory is converted to fission products in the fuel elements. The radiological safety of both plant personnel and the public in the vicinity of the nuclear power plant, obviously, depends on maintaining control of these fission products.

The primary objective of nuclear power plant design is to maintain positive control over all radioactive materials under both normal and abnormal operating conditions.

A) Fission Product Containment

To assure that no course of events can lead to a significant release of radioactive material, the fission products generated by nuclear power plants are contained within three barriers. First, all fission products are held within fuel-element cladding, which is designed to withstand the high temperature and irradiation conditions within the reactor core. Should a leak or loss of the fuel-element cladding integrity occur, the reactor coolant system provides a second containment boundary. This containment boundary is also designed to withstand high-temperature, high-pressure, and high-irradiation levels. The coolant within this system is constantly monitored to provide prompt detection of significant fuel-element failures. In the event that this second boundary layer should be ruptured, a third independent, overall containment capability, a containment shell enclosing the entire reactor is provided for all nuclear power plants. This containment capability is designed to function under conditions imposed by the worst hypothetical accident that can be reasonably postulated and such natural environmental stresses as seismic or tornado loads, and to hold essentially all radioactive material resulting from any reasonable combination of accident forces. This containment shell and associated safeguards systems are tested before operation commences and periodically throughout operating life of the nuclear power plant.

The reactor coolant system provides the second containment boundary for the fission products. Maintaining the integrity of this boundary is a prime safety objective in the design, fabrication, and operation of nuclear power plants. Retention of the reactor coolant within this boundary in many designs also permits limited core heat removal (cooling of the fuel) even in the event of substantial reduction of coolant flow.

Despite the assurance that a high-integrity coolant boundary is provided for these plants, a further line of defense is incorporated to protect the public in the unlikely event of a failure of this boundary. If the reactor coolant boundary were to break, the fuel would overheat and possibly melt if coolant were reintroduced in a very short time. To achieve emergency core cooling nuclear plants are furnished with a sophisticated emergency core cooling system which can accommodate a wide range of potential cooling system failures.

In accordance with the philosophy of doing everything possible and practical to insure the public safety, additional systems are provided against the release of fission products. These generally fall into three categories: containment and confinement, pressure reduction, and air-cleaning systems.

By far the most familiar safeguard is the reactor shell containment system, which is in addition to the built-in containment factors. This is basically a pressure shell, designed to retain the energy stored in the reactor coolant or generated by chemical radiolytic reactions, and the radioactive materials which might be released as a consequence of an accident. This barrier can be fabricated of steel or reinforced or prestressed concrete; it may be a single or double barrier; and it may be maintained at normal atmospheric pressure or at subatmospheric pressure.

Various accessories and auxiliaries are incorporated into the containment: access openings and closures including air locks for personnel, ventilating air inlets and isolation valves, penetration seals for pipes and electrical leads, and valves for closing pipes which penetrate the containment. Shrapnel shields are included for protection against missiles which accidents can create. These safety systems are designed with special features for protection against earthquakes and high winds.

B) Containment Systems Reliability

The reliability of containment and other engineered safeguard systems is an important factor in the overall safety of nuclear power plants. A system which appears highly effective under carefully controlled conditions is worse than useless if it cannot be counted upon to function when needed.

In designing engineered safeguards for maximum reliability, several factors are considered. Static systems and devices are used whenever possible rather than those which require electrical or mechanical action. Mechanical devices are designed to fail in the safe position, so protection will not be lost during power failure or other malfunction. They are also designed to operate after long periods of inactivity. And, an obvious point which should not be overlooked, safeguard systems need to be designed to operate under accident conditions--not just under idealized design and test conditions.

For the critical subsystems upon which the entire operation of the containment system depends, multiple or redundant systems are required. This is particularly true for instrumentation which senses that an accident has occurred, provides an alarm, or initiates protective action. A highly reliable mechanical device is of no use if the sensors, circuitry and/or power supply which cause it to function are unreliable. Spurious signals which cause a safety system to actuate in error could cause severe operating difficulties. For these reasons, several independent sensors, sometimes operating in coincidence, may be used to automatically actuate a safeguard device or provide an alarm. Two complete and independent containment-closure devices (and associated control systems) may be used in certain critical areas, such as for isolating an open containment ventilation system.

Ideally, all safeguard systems should use components which are normally in operation, thus continuously used and their functioning noted. However, containment systems and several other components of engineered safeguards systems are not normally called upon to function; hence, their action is not checked by normal operation. It is, therefore, particularly important that careful inspection, testing, and maintenance of these safeguard systems be carried out to assure their continued operability and effectiveness. This implies that adequate administrative and technically sound procedures for performing these functions are available, and the control necessary to assure that these procedures are followed is exercised.

C) Design Basis Accident

The limiting, or hypothetical, accident model used by the USAEC is defined in 100CFR100, "Reactor Site Criteria." This model, which deals with a loss-of-coolant accident, is referred to variously as the "maximum hypothetical accident" or "design basis accident" (DBA). It assumes an instantaneous severance of the largest pipe in the coolant system, postulates a melt of a gross amount of the fuel, and neglects the effects of emergency core-cooling systems and any population control measures. To deal with the release, a combination of consequence-limiting safeguard systems is required, which need to be sufficient to reduce the calculated doses to people in the neighborhood of the plant to prescribed levels, normally 25 rem whole body exposure and 300 rem thyroid exposure.

In making the calculation the fission product releases into the reactor building containment are specified to be 100% of the equilibrium core inventory of noble gases, 50% of the halogens, and 1% of the solids in the fission product inventory. Of the released halogens, 50% are assumed to deposit on the surfaces inside containment, leaving only 25% of the core inventory available for leakage. In actuality, such a release could not occur unless all the redundant emergency core-cooling systems malfunction. The combined probability of both these failures and the pipe rupture is so small as to be numerically indefinable. It is certainly much smaller than similar failure probabilities in other engineered structures such as dams, aircraft, bridges, and chemical process equipment, whose failure would have major safety implications.

Meteorological circumstances presumed to exist at the time of the accident represent those least favorable at the site under consideration for transport and diffusion of released gases and vapors--usually a moderately severe inversion coupled with light winds, which are assumed to be invariant in direction during the first phase of release.

Protection is assumed to be afforded only by the so-called "passive" systems; i.e., those for which no system action is required, such as the containment system. Limited or partial protection is credited to such active consequence-limiting systems as sprays and charcoal filters, in which pumps, blowers, valves, etc., are required to operate. No credit is granted for evacuation or other population protection measures which may be executed in a reasonable period of time.

With these extremely stringent ground rules for evaluation, nuclear plant sites and the associated engineering safeguard systems need meet the dose criteria specified. Obviously, actual exposures to members of the public would be very much less, if only because of the functioning of duplicate plant safeguard systems (which are provided in replicate and required to be tested periodically throughout the plant life). Other emergency measures would be brought into play depending upon the condition of the plant and the actual dispersion conditions which existed at the time.

The philosophy of design and safety assessment used by the nuclear power industry, which postulates a design basis accident to define boundary conditions, provides a built-in mechanism for public misunderstanding. If safety systems are required, and then assumed not to function so that subsequent consequences can be examined, the hypothesis can easily be taken as a vote of no confidence in reliability and availability. This, in fact, appears to be the case. Since this approach to safety assessment, which has provided a high degree of public safety, is not found in other similar industrial activities, a problem is created which needs to be faced by the nuclear power community: to explain to the public the nature and benefits of these assessments. Unless such explanation can be made and accepted by the public, the difficulties that result from this rigorous self-appraisal technique appear likely to continue.

D) Radioactive Waste Generation

Radioactive waste at a nuclear power station is produced as a by-product of the fission process within the fuel element and from neutron activation of structural materials, corrosion products, and coolant impurities within the reactor vessel. The characteristics of the radioactive waste from a particular power plant are highly dependent on the type of reactor system used. Naturally, the characteristics of wastes strongly influence the design of a particular waste-treatment system.

The quantity of fission products within the reactor fuel element depends upon 1) the average power level of the reactor, 2) the fuel residence time in the core, and 3) the time transpired for radioactive decay. Typically, about 1.8×10^6 curies of radioactive fission products would be in the reactor core per megawatt of reactor power one hour after shutdown following a two-year operating cycle. At one day after shutdown, the activity would decay to about 10^6 Ci/megawatt; the inventory of the most biologically significant radionuclides for this operating history is shown in Table I. Shorter irradiation times result in lower inventories; however, after a few weeks of operation, the fission-product inventory of tritium is produced within the reactor fuel element by ternary fission.

In addition to the fission products generated within the fuel elements, small quantities of radioisotopes--such as those of iron, chormium, cobalt, and maganese--are produced from neutron activation of corrosion products which normally form during reactor operation. Normally these isotopes are entrained in the circulating coolant. Both soluble and insoluble compounds of these radionuclides are formed. They usually can be removed from the coolant by appropriate use of filtration, ion exchange, and evaporation. The reactor coolant water itself is subject to neutron activation, producing small quantities of ^{16}N. The introduction of boron and lithium in the coolant of pressurized water reactors to control core reactivity has the simultaneous effect of generating tritium by neutron absorption by the boron.

TABLE 1

Inventory of Selected Radionuclides Following Two-Year Operation with 1-Day Decay

Selected Isotopes	Half-Life	Activity in Fuel kCi/MWt
^{3}H	12.3 yr	0.0043
^{85}Kr	10.7 yr	0.25
^{89}Sr	51 days	24
^{90}Sr	28.9 yr	1.8
^{90}Y	64 hr	1.8
^{91}Y	58.8 days	32
^{99}Mo	66.6 hr	40
^{131}I	8.06 days	28
^{133}Xe	5.3 days	54
^{134}Cs	2.06 yr	0.61
^{132}Te	78 hr	34
^{133}I	20.8 hr	22
^{136}Cs	13 days	0.74
^{137}Cs	30.2 yr	2.4
^{140}Ba	13 days	46
^{140}La	40.2 hr	49
^{144}Ce	284.4 days	35

E) Radioactive Waste Management

The typical nuclear power plant design objective is to process and recycle waste streams so as to minimize both volume and radioactivity of effluents wherever practical. Releases to the environs are controlled by batch processing and/or continuous monitoring before discharge to assure that no release will exceed established limits.

The waste management techniques in current use for gaseous waste are: (1) holdup and decay, (2) filtration, and (3) cryogenics. Holdup and decay refer to storing waste long enough to decrease the associated treatment problem or hazard by permitting some radioactive decay to occur before release. The usefulness or efficacy of this technique as a means for reducing activity levels in gaseous wastes depends on the particular isotopes present. In a typical boiling water reactor, BWR, an overall decontamination factor (DF) of 48 may be expected from a 30-minute delay for a representative gas mixture.

Reservoirs intended to achieve gas holdup times of several days or more need to be designed in such a manner to assure that the gas is not released prematurely as a result of mixing gases generated at different times. The design should, therefore, utilize either very long, narrow passages to minimize mixing effects or alternately, a series of separate chambers which are filled, left undisturbed for a predetermined time, and then discharged sequentially. In either event, the volumetric storage capacity of such a system should be roughly proportional to the delay time selected.

Filters collect radioactive solid particles formed when a gaseous parent nuclide decays to a particulate radioactive daughter. The performance of High-Efficiency Particulate Air

(HEPA) filters is well documented. Tests run have indicated removal efficiencies of 99.97% as a minimum for typical HEPA filters. For maximum effectiveness, HEPA filters should be placed where the particulate concentration is highest. For off-gas systems in water-cooled reactors, this location is just below the point in the stack from which the gas is released, thus allowing a maximum of transport time for gaseous radionuclides to decay to particulate daughter products before filtration.

Liquid waste management systems currently employ four basic treatment techniques to reduce levels of radioactivity. These techniques are: (1) holdup and decay, (2) filtration, (3) evaporation, and (4) demineralization. A final reduction in liquid radionuclide concentrations is achieved by dilution of the wastes in the condenser cooling water to insure that radionuclide concentrations are at the lowest level possible before reaching the site boundary.

Holdup and decay for liquid waste is identical in principle to that for gaseous waste, although little reduction in liquid radioactivity levels is accomplished by this method. Radionuclides found in liquid radioactive waste have relatively long half-lives, since short half-life radionuclides decay away in the time it takes for their transfer through the plant. A relatively long holdup time would be needed to achieve any appreciable reduction in liquid-waste radioactivity levels--it is estimated that approximately 40 days would be required to reduce typical liquid waste radioactivity levels by about a factor of 5. Filtration is usually utilized as the sole means of radioactive waste treatment for waste streams containing primarily insoluble or particulate contaminants.

Evaporation separates water from nonvolatile dissolved and insoluble radioactive wastes by boiling. This results in a concentration of the wastes, permitting easier ultimate disposal. The efficiency of evaporation for radioactive waste treatment can vary widely, depending on the radioactive materials present. Overall DF's of 10^2 to 10^5 (between feed and condensate) are experienced, depending on the mass velocity of the vapor in the evaporator and decontamination efficiency for nonvolatile radioactive contaminants. If volatile radioactive materials such as tritium, iodine, or ruthenium are present, the overall EF may be substantially reduced, due to carryover of these materials.

The efficiency of ion-exchange treatment of waste streams depends on the type, composition, and concentration of waste liquid, the type of exchanger, regeneration methods, radionuclides present, and operating procedures. Decontamination factors as low as 2 and as high as 10^5 are reported. Only low total dissolved and suspended solids waste can be processed efficiently by ion exchange, because bed exhaustion occurs rapidly for liquids with a high total dissolved-solids content. Also, suspended solids will clog an ion exchanger and prevent its efficient operation. Thus, the use of ion-exchange treatment needs to be restricted to radioactive wastes with low total dissolved solids and low suspended solids.

Dilution of liquid wastes and gases has been used to bring the concentration of radionuclides within acceptable limits for discharge. This approach is based on the premise that concentration needs to be maintained below specified values to control both direct ingestion and indirect ingestion of aquatic or marine species whose radioactivity uptake is directly proportional to the discharge concentration. If the receiving body of water is restricted, as in the case of a cooling pond or lake, dilution becomes less useful. The total quantity of radioactive material released in this case needs to be decreased due to accumulation and recyling of the effluent stream.

ENVIRONMENTAL SURVEILLANCE

All facilities which have a significant potential for environmental contamination require some degree of environmental surveillance.

Nuclear power plants will normally have process controls and equipment designed to limit the release of radioactive material to the environs, and provisions for monitoring of the liquid and gaseous effluents. Depending upon the nature and quantities of radionuclides being released an environmental surveillance program around such facilities may range in complexity from simple confirmation of the effluent monitoring results up to a complex network of field measurements, sampling and laboratory analysis.

A) Objectives of Environmental Surveys

Several objectives often stated for environmental survey programs are listed in Table 2.

TABLE 2

Purposes of Environmental Surveys

1. Radiological Protection of People
2. Audit Containment Systems and Effluent Monitoring
3. Maintain Public Acceptance of the Nuclear Facility
4. Fulfill Regulatory Requirements
5. Legal Protection from Liability Actions

The primary consideration should be radiological protection of the public. The other considerations relate to the primary objective since the purpose of regulatory requirements is primarily radiation protection. Two others often mentioned as objectives are both related to public relations--maintaining public acceptance of the nuclear facility and gathering of data for protection against liability claims. In nearly all instances an environmental survey program designed around the primary objective of radiological protection will either satisfy the other objectives or can be made to satisfy them with only slight additions and alterations.

Overly elaborate environmental monitoring programs are not only economically unsound but excessive sampling and measurement in the environs might arouse unwarranted fears in the public.

In the early days of the atomic energy program it was not always possible to relate the environmental monitoring data to a parameter that could be used to express actual population risk. Early programs consisted of sampling and analyzing environmental media, seeking for radioactivity and attempting to explain its presence there. Today it should be possible to relate radioactivity in the environment to radiation exposure of people and thus to evaluate the impact of a nuclear facility in terms of the radiation dose received by residents in the vicinity of the plant.

B) Development of Environmental Surveillance Program

If the objective of the surveillance program is to ensure that acceptable doses are not exceeded, measurements need to be made which will allow tissue doses to be calculated. It follows that the most profitable measurements will be those which can be made on the materials which provide a direct source of exposure, whether air, water, food or some other material. In certain cases, however, measurements on materials, which do not constitute a direct source of exposure to man but which are good indicators of environmental contamination, can be used to evaluate the trend of this contamination.

Development of the surveillance program needs to start with the facility itself, work through the environmental and population factors operating between the points of release and the points of public exposure, should consider the potential radiation doses to the public, and then should come full circle back to the facility by relating public exposure to specific release rates of the various radionuclides involved. Table 3 illustrates the evaluation of radiation dose and the related environmental measurements.

The first column in the table lists five principal steps in the process, the second column lists the factors to be considered at each step, the methods of evaluation are given in Column 3, and the last column indicates the standards against which the results of the evaluation are to be compared.

Step A requires a thorough knowledge of the facility itself--what processes are involved? What radionuclides are to be released routinely and in what quantities? How are they to be released? Are the methods chosen for effluent monitoring sufficient to evaluate the potential impact of the routine releases in the environs? What is the potential for accidental release of additional radionuclides or of greater quantities than normal? Will accidental releases be detected accurately and rapidly enough to permit proper environmental assessment and control?

Step B involves knowledge of the environment and the possible interaction of the environment with the released material. Studies of the meteorology, hydrology, and aquatic and terrestrial biology of the environs are required to determine the behavior of the particular chemical and physical forms of the radionuclides released. The behavior after release, of course, can be monitored by sampling of environmental media such as air, water, foods, soil and sediment.

TABLE 3

Evaluation Chart - Environmental Population Dose

	Step	Factors	Evaluation	Standards
A.	Release	Concentration Rate of Release	Measure Effluent	Release Guides
B.	Dispersion, Reconcentration	Meteorology, Biology, Hydrology, Physical and Chemical Forms	Measure Environmental Media - Air, Water, Foods	Fraction of MPC_w or MPC_a (Concentration Factors)
C.	Intake	Air, Concentration, Water, Consumption Food, Rate	Diet Surveys, Studies of the Uses of Environs	ICRP - μCi/day
D.	Retention	Percent Uptake, Biological Half-Life, Distribution in Body	Bioassay, Whole-Body Counting	MPBB's
E.	Dose	Body Dimensions, QF, DF, Rads/μCi	Calculate Doses to Maximum Individual, Population Average Adult, Child	10-CFR-20 AEC Manual, NCRP, ICRP

Step C is related to determination of the human factors which influence the impact of the released material. What are the dietary habits of the local population? What are the sources of their food? What recreational habits might affect their exposure? If data are not readily available to answer these questions, then special studies may have to be undertaken to gather them.

The last two steps, Steps D and E, normally involve only paper studies utilizing the data available from the previous steps. Using the parameters defined by the ICRP for the Standard Man and the literature data on physiological parameters of other ages, one can estimate the long-term accumulation of radionuclides in the body from the intakes previously derived. Then the radiation doses can be calculated for comparison with the appropriate guides and standards. Confirmation of retention and accumulation of radionuclides in the body, when these represent a significant fraction of the maximum allowable amounts, can be made through in vivo or whole-body counting of appropriate members of the general public.

Once these doses are estimated one can proceed back up the last column of the evaluation chart deriving the maximum allowable releases of the radionuclides and establishing the relationship between actual release and potential doses to people. If it turns out that the releases are only a small fraction of those which would result in residents receiving the maximum allowable doses, then environmental monitoring can be limited to a few simple measurements of indicator materials to confirm the effluent monitoring results.

On the other hand, if the releases are such that the radiation doses received by the public will closely approach the limiting values, then a comprehensive program of sampling and analysis of air, water, foods, soil and external dose rates needs to be instituted. The foregoing review in terms of radiation dose and the environmental and human factor influencing the behavior of the radionuclides should have identified the "critical" nuclides and "critical" pathways of exposure which need to be monitored.

After an environmental monitoring program is established it should be reviewed periodically to ensure that it is properly formulated and that it still is meeting its objectives. Experience may have reaffirmed relationships between quantities released and environmental measurements, allowing for a reduction in the scope of the surveillance program, or the nature and quantities of radionuclides released from the facility may have changed requiring a shift in the emphasis of the environmental program.

C) Radiation Guides and Standards

The International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurement (NCRP) have been active in the development of standards for protection against ionizing radiation for the past forty years.

Figure 1 illustrates the current radiation standards for the general public as spelled out by the USAEC. Two sets of limits are quoted--one for controlling the exposure to an individual member of the population and the other for the average exposure to the general public. The whole-body limit for the general population can be derived from the recommendation that the dose to the gonads be limited to a total of 5000 mrem up to the mean reproductive age of 30 years.

The principal limit promulgated by the USAEC for nuclear facilities has been the one of 500 mrem/year to the whole body of an individual. Because of the geographical location of nuclear facilities in relation to the surrounding populations, it is not feasible to imagine a situation where the average exposure to a significant number of people could approach the limit of 170 mrem/year.

The ICRP, in their publication 7, have discussed environmental monitoring and have defined the critical population group whose radiation exposure is to be compared against the recommendations for the maximum permissible doses for individual members of the public. Their definition is -

> "The critical group should be identified in such a way that it is representative of the more highly exposed individuals in the population and is as homogenous as practicable with respect to radiation dose; that is, with respect to those factors which affect the dose in the specific case considered."

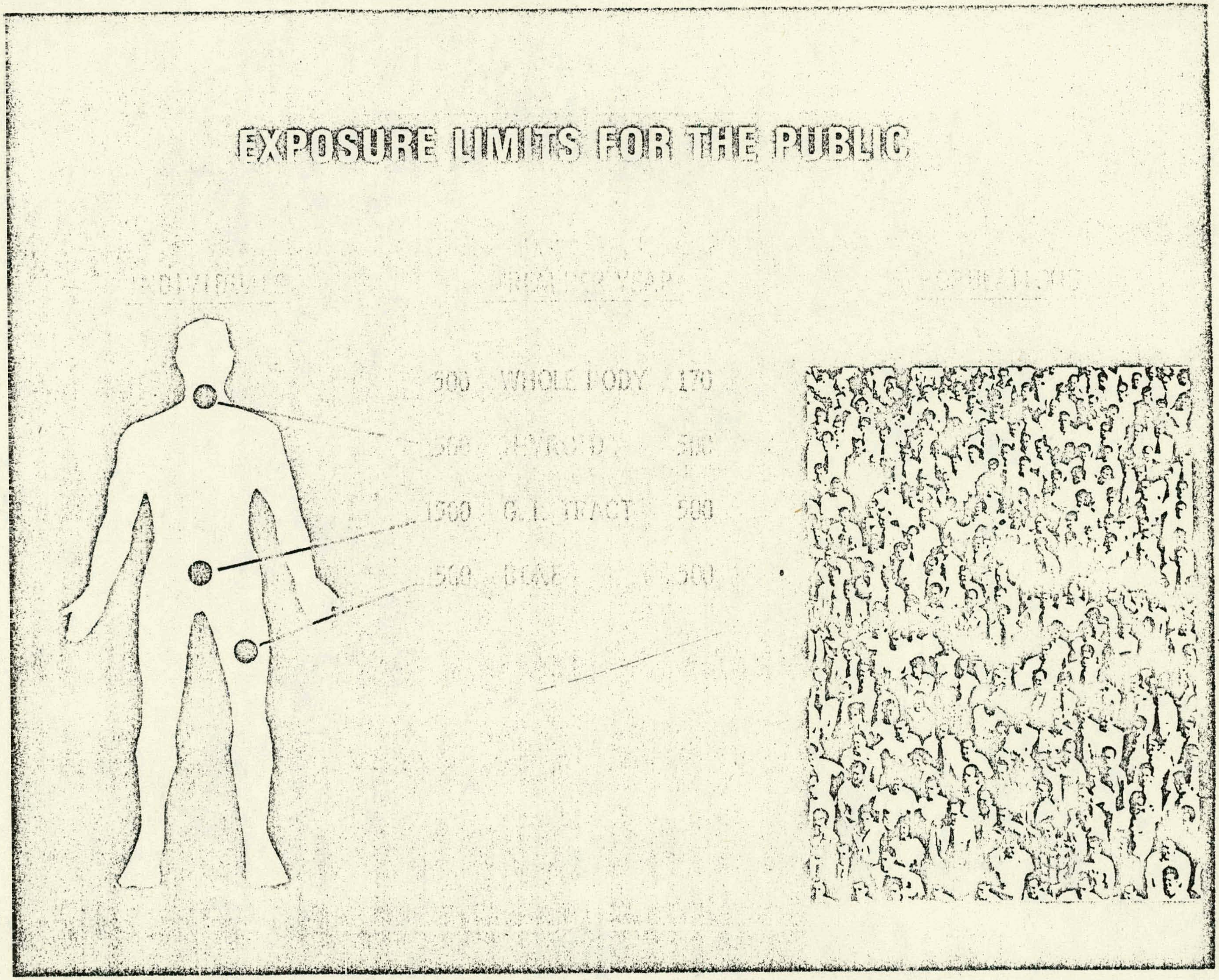

EXPOSURE LIMITS FOR THE PUBLIC
500 WHOLE BODY 170
1500 G.I. TRACT 500

Figure 1

D) Pathways of Environmental Exposure

The principal pathways by which radioactive materials released to the environs can reach and expose people are illustrated in Figure 2. Included in this figure are the environmental parameters (Step B) and the human parameters (Step C) mentioned in Table 3.

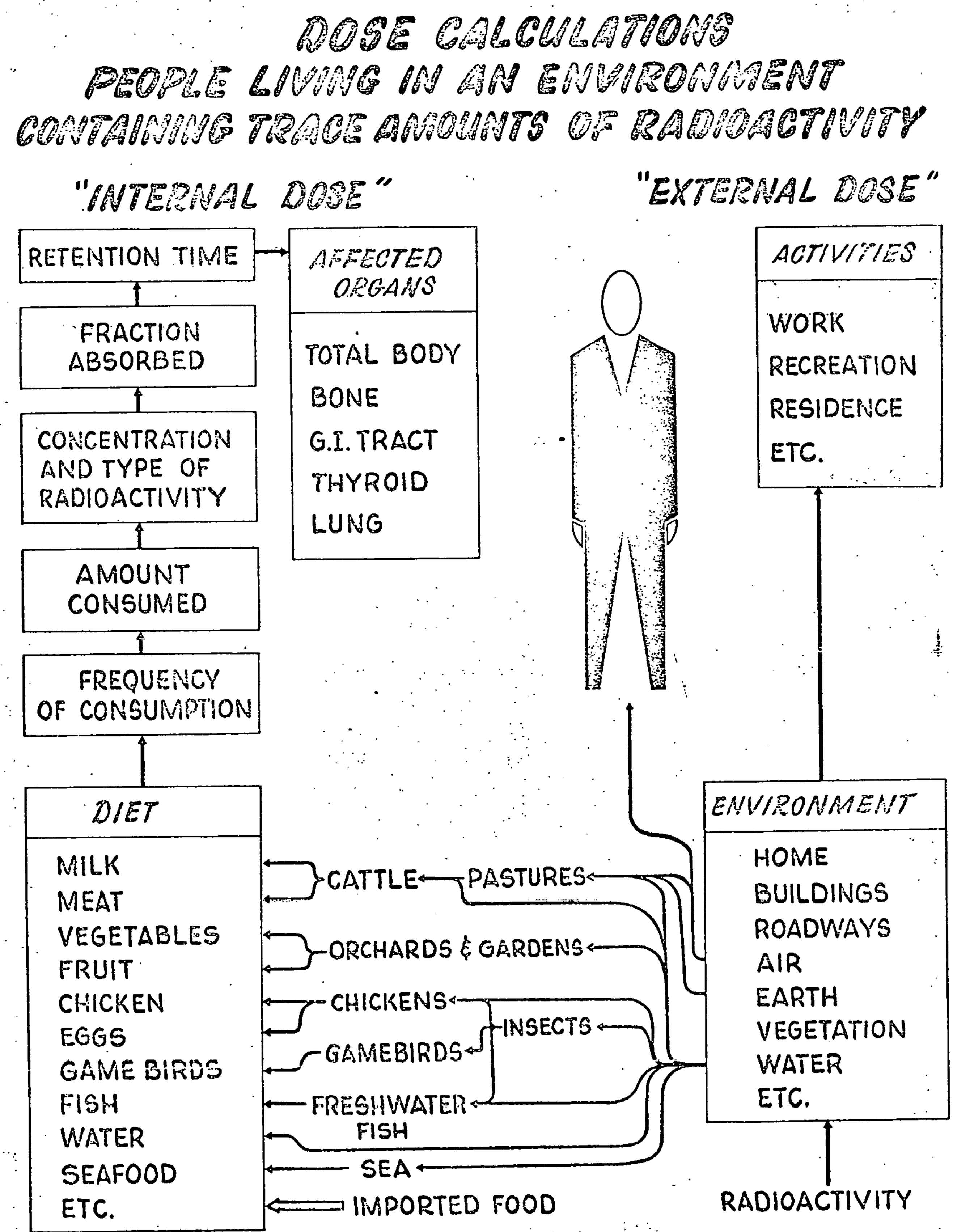
External exposure can be received from exposure to the cloud of radioactive gases released from a nuclear facility, from swimming or boating in and on waters contaminated from liquid effluents, contact with ground or objects contaminated via deposition from airborne or waterborne radionuclides.

Internal dose can result from inhalation of air or ingestion of water and foods containing the released radionuclides. The pathways by which the foods become contaminated from releases to air and water are also shown. For example, chickens could ingest radioactive materials with their drinking water, with insects, or with feed grown on contaminated ground or irrigated with contaminated water.

Detailed studies of the behavior of radionuclides in the several environmental media are not always available, but much is known at least in general terms about the most important radionuclides. Habits of the local population which might affect their radiation dose vary with each individual site and should be determined before the environmental survey is designed.

State and Federal agriculture, recreational, and fish and wildlife agencies can be of assistance in defining these parameters. Sometimes special studies of the local population are required, especially if specific critical pathways are involved. Examples of the latter include the consumption of Laverbread by persons in the vicinity of the Windscale facility in the U. K., consumption of oysters in the vicinity of the

Figure 2


DOSE CALCULATIONS
PEOPLE LIVING IN AN ENVIRONMENT
CONTAINING TRACE AMOUNTS OF RADIOACTIVITY
"INTERNAL DOSE"
"EXTERNAL DOSE"
RETENTION TIME
FRACTION ABSORBED
CONCENTRATION AND TYPE OF RADIOACTIVITY
AMOUNT CONSUMED
FREQUENCY OF CONSUMPTION
AFFECTED ORGANS
TOTAL BODY
BONE
G.I. TRACT
THYROID
LUNG
ACTIVITIES
WORK
RECREATION
RESIDENCE
ETC.
DIET
MILK
MEAT
VEGETABLES
FRUIT
CHICKEN
EGGS
GAME BIRDS
FISH
WATER
SEAFOOD
ETC.
CATTLE
PASTURES
ORCHARDS & GARDENS
CHICKENS
INSECTS
GAMEBIRDS
FRESHWATER FISH
SEA
IMPORTED FOOD
ENVIRONMENT
HOME
BUILDINGS
ROADWAYS
AIR
EARTH
VEGETATION
WATER
ETC.
RADIOACTIVITY

Bradwell nuclear power station, U. K. and the consumption of Columbia River fish harvested downstream of the USAEC's production reactors at Hanford. These three examples are illustrated in Figures 3, 4 and 5.

E) Environmental Surveillance Programs

1) Preoperational Surveys

The operator of a nuclear establishment is held responsible only for that radioactive material which the particular plant has added to the environment. To assess his contribution it may be necessary to interpret the results of operational surveys in the light of pre-existing levels of radioactivity in the environment.

Other sources of environmental radiation and contamination are:

(i) Naturally occurring radiation and radioactive materials;

(ii) Fall-out from nuclear explosions;

(iii) Nuclear establishments other than the operator's.

Preoperational measurements of radioactivity in the environment may occasionally reveal unexpected local environmental radioactivity which could otherwise have been attributed to the operation of an establishment. Perhaps the most important function of a preoperational survey is to train staff in sampling and analytical techniques. To do this, methods used in a pre-operational survey for radioactivity should be identical with those to be used in the routine surveys.

Samples of air, water, soil and plant and animal life should be collected and analyzed for those radionuclides which will be of interest when the facility becomes operational.

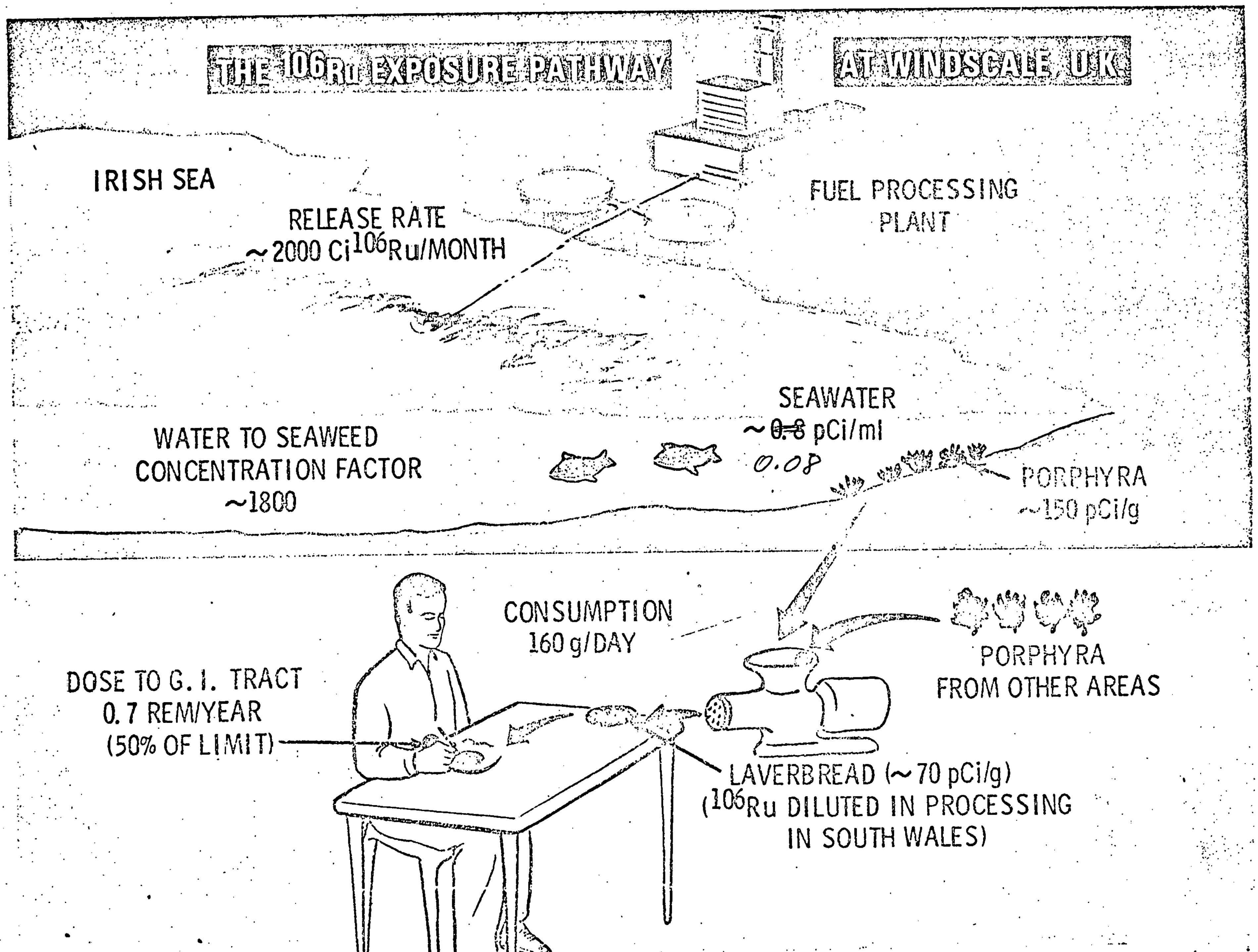

THE ^{106}Ru EXPOSURE PATHWAY
AT WINDSCALE, U.K.
IRISH SEA
RELEASE RATE
~2000 Ci ^{106}Ru/MONTH
FUEL PROCESSING PLANT
SEAWATER
~ ~~0.8~~ pCi/ml
0.08
WATER TO SEAWEED CONCENTRATION FACTOR
~1800
PORPHYRA
~150 pCi/g
CONSUMPTION
160 g/DAY
PORPHYRA FROM OTHER AREAS
DOSE TO G. I. TRACT
0.7 REM/YEAR
(50% OF LIMIT)
LAVERBREAD (~70 pCi/g)
(^{106}Ru DILUTED IN PROCESSING IN SOUTH WALES)

Figure 3

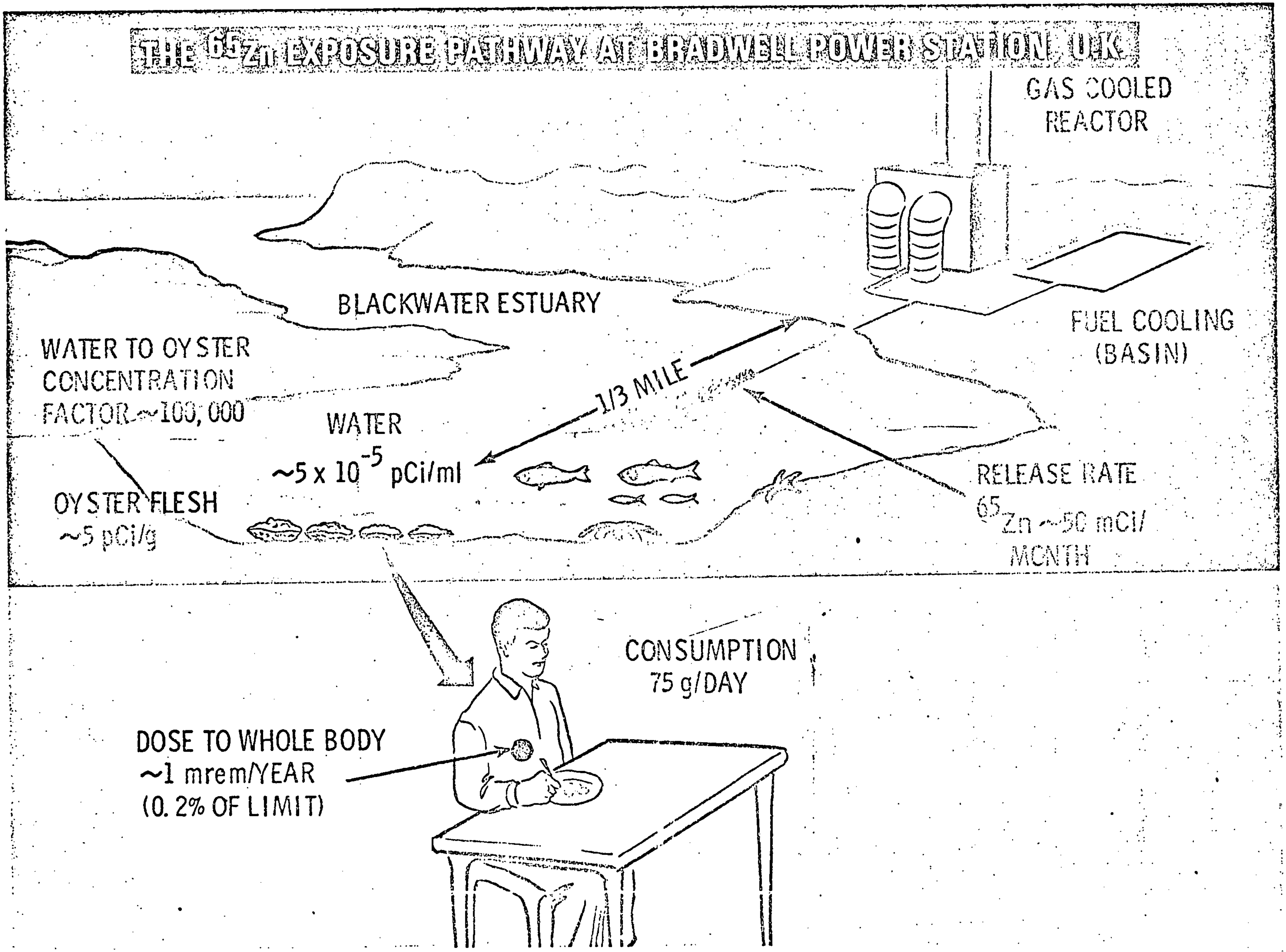

THE ^{65}Zn EXPOSURE PATHWAY AT BRADWELL POWER STATION, U.K.
GAS COOLED REACTOR
BLACKWATER ESTUARY
FUEL COOLING (BASIN)
WATER TO OYSTER CONCENTRATION FACTOR ~100,000
1/3 MILE
WATER
~5 x 10^{-5} pCi/ml
RELEASE RATE
^{65}Zn ~50 mCi/MONTH
OYSTER FLESH
~5 pCi/g
CONSUMPTION
75 g/DAY
DOSE TO WHOLE BODY
~1 mrem/YEAR
(0.2% OF LIMIT)

Figure 4

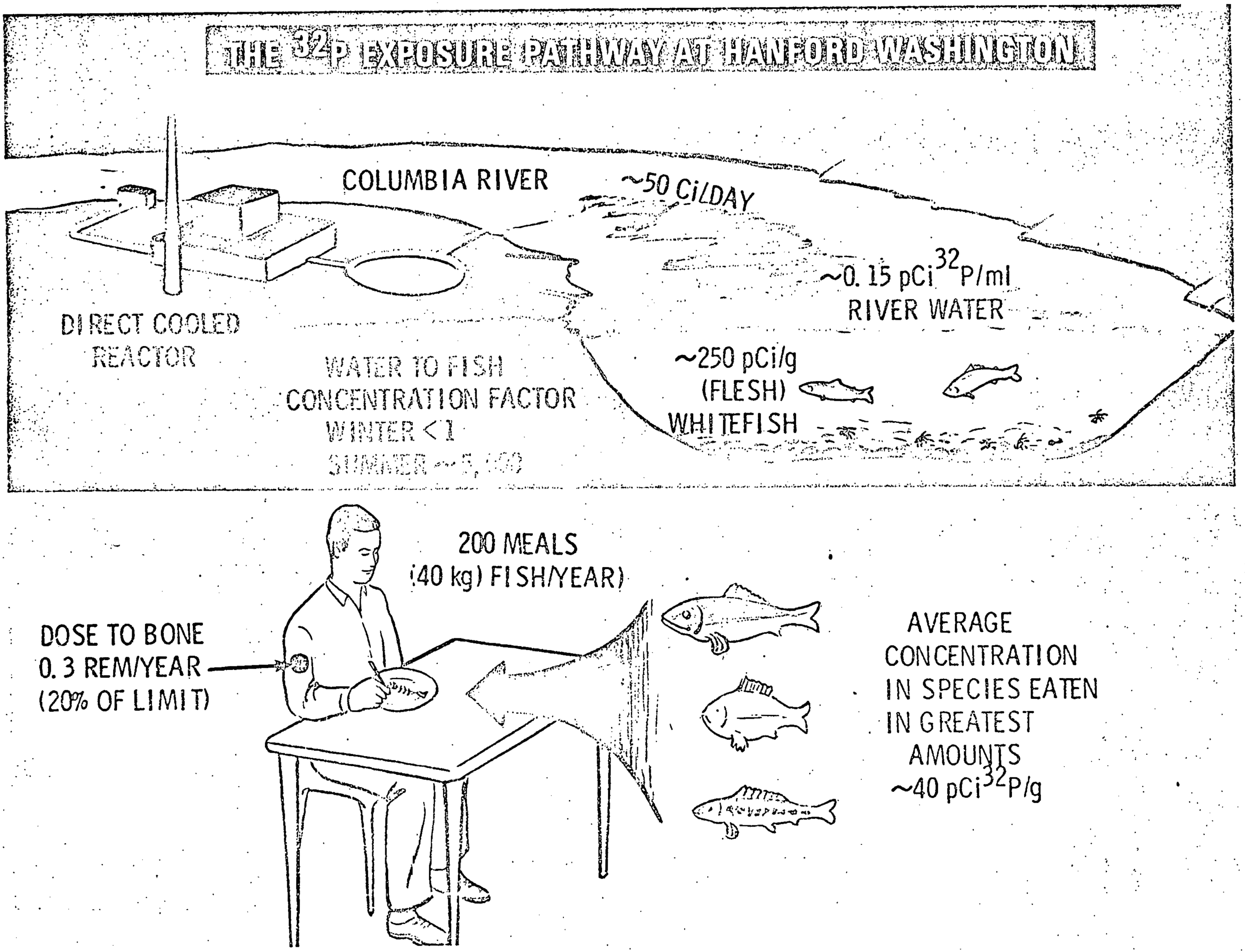

THE ^{32}P EXPOSURE PATHWAY AT HANFORD WASHINGTON
COLUMBIA RIVER
~50 Ci/DAY
DIRECT COOLED REACTOR
~0.15 pCi ^{32}P/ml RIVER WATER
WATER TO FISH CONCENTRATION FACTOR
WINTER <1
SUMMER ~5,
~250 pCi/g (FLESH) WHITEFISH
200 MEALS (40 kg) FISH/YEAR)
DOSE TO BONE 0.3 REM/YEAR (20% OF LIMIT)
AVERAGE CONCENTRATION IN SPECIES EATEN IN GREATEST AMOUNTS ~40 pCi ^{32}P/g

Figure 5

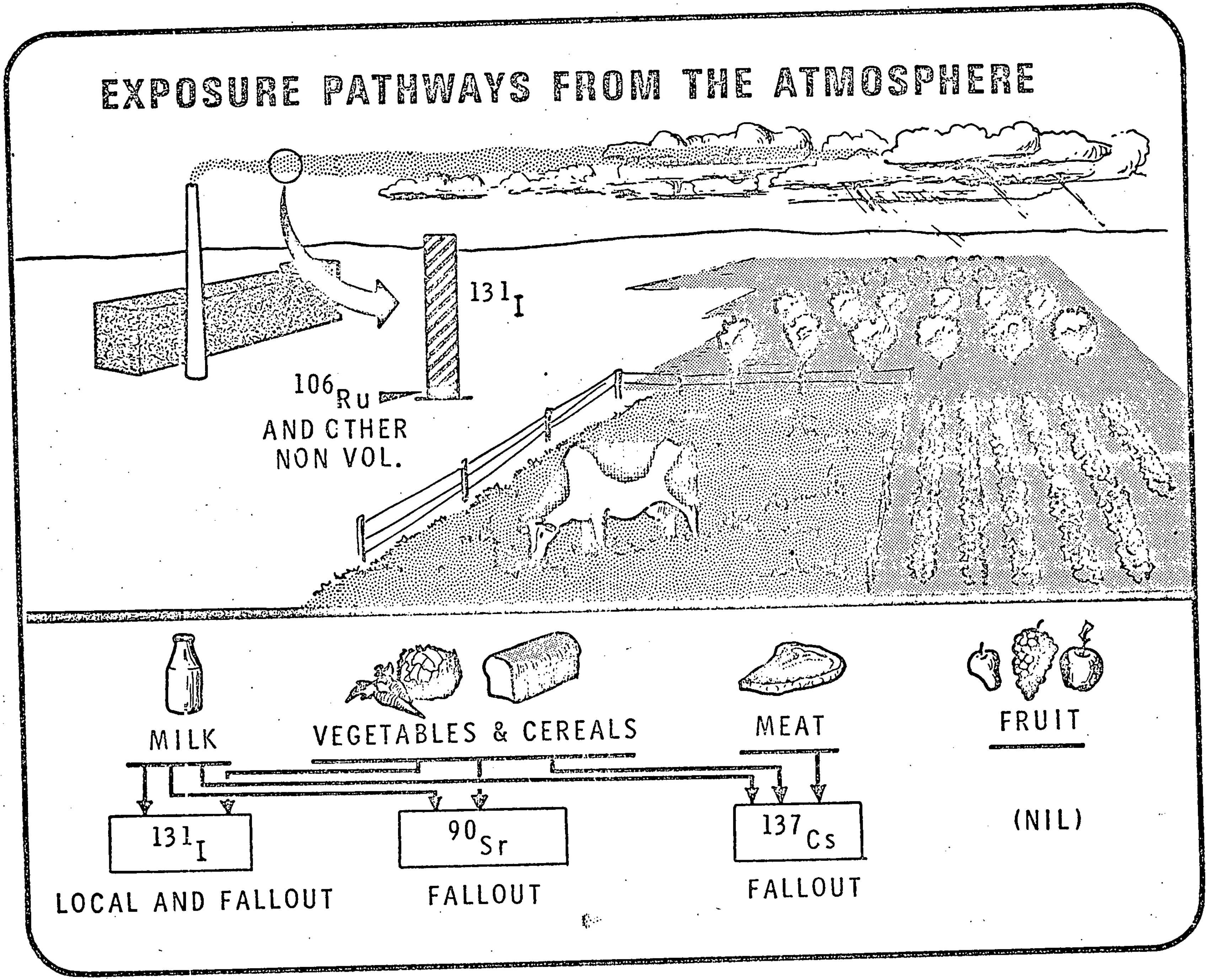

EXPOSURE PATHWAYS FROM THE ATMOSPHERE
^{131}I
^{106}Ru
AND OTHER
NON VOL.
MILK
VEGETABLES & CEREALS
MEAT
FRUIT
^{131}I
LOCAL AND FALLOUT
^{90}Sr
FALLOUT
^{137}Cs
FALLOUT
(NIL)

Figure 6

In preoperational surveys around reactors, it may be sufficient to measure external gamma dose rates, gross beta or gamma activity in air, water, soil and biological materials. A few measurements for ^{90}Sr might be made to determine the contribution from fallout.

Also included should be measurements of meteorological and hydrological parameters likely to effect the dispersal of released effluents. The survey should extend over a period of 12 to 18 months, and include two growing seasons. By the time the facility is operational, the particular vegetation, animals, water sources, etc., likely to concentrate released nuclides should have been indicated. Routine operational surveys can be designed on the basis of this information.

2) Operational Surveys

Data gathered during environmental surveys performed after a nuclear facility begins operation can be used to evaluate the effluent controls. For larger installations releasing significant quantities of radionuclides to the environs, the data should also be used to estimate the radiation doses received by the population residing nearby. Discharge data should be available to those responsible for environmental surveillance whether these persons are a part of the operator's organization, a separate company, or a state or federal health agency. Availability of such data is necessary if the relationship between radioactive discharges and environmental survey results is to be established.

a) Monitoring related to releases to the atmosphere

Figure 6 illustrates some of the environmental media which might be sampled to determine the human exposure resulting from releases of radioactive materials to the atmosphere. Gamma radiation, either directly from the released cloud or from material deposited on the ground can be measured by

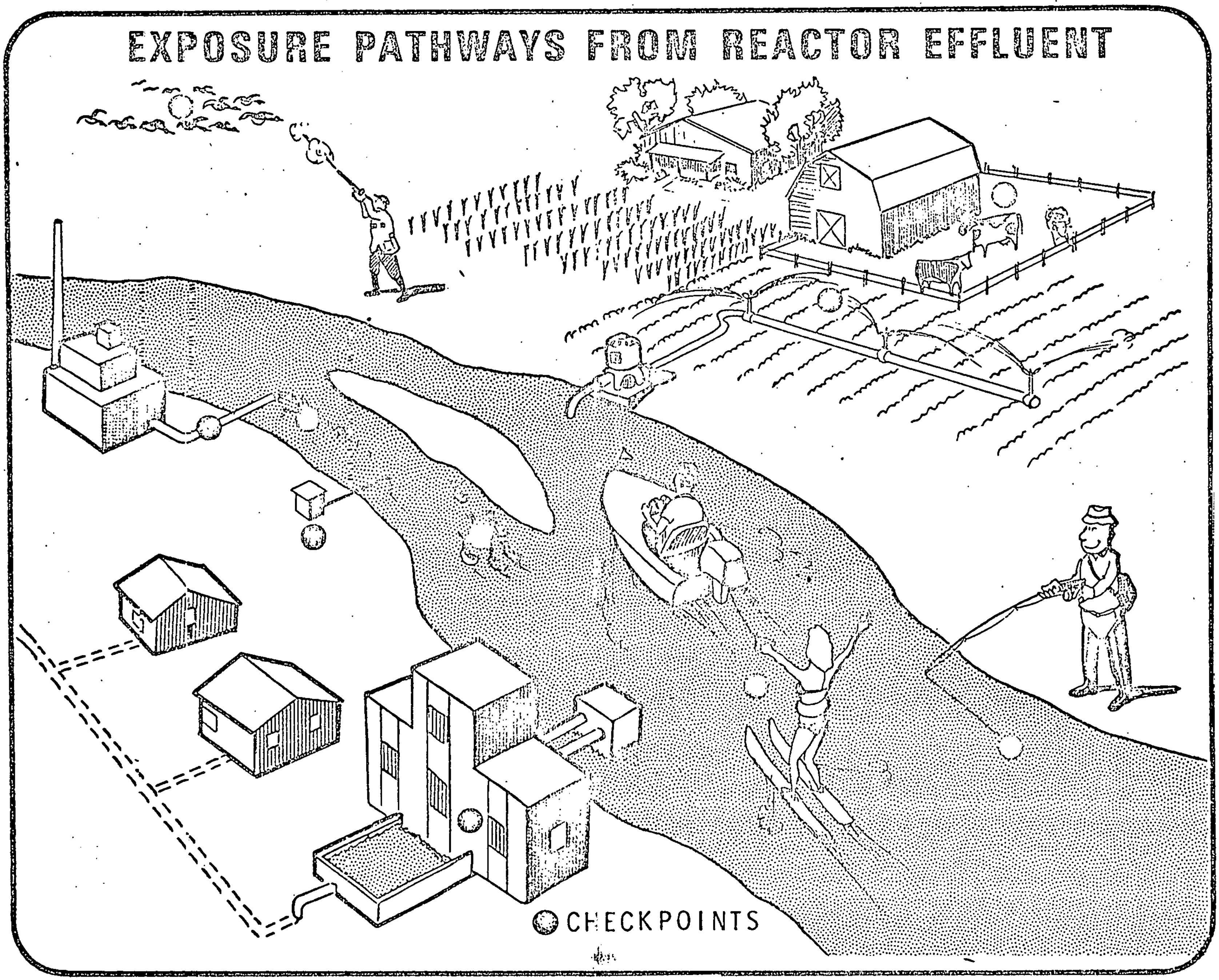


Figure 7

integrating type dosimeters continuously exposed at a fixed station and then read periodically. The biggest difficulty is to detect small changes in the background exposure rates (which normally range from 10 to 20 μR/hr).

In the past, attempts have been made to use standard personnel dosimetry film for these measurements. However, the film is not sensitive enough to detect the small incremental doses from the plant without exposure periods of a month or more. During this long period high temperatures and excessive moisture often caused erratic, high results.

Energy compensated G.M. Tubes have also been used to measure (and record) ambient gamma exposure rates. Here again the sensitivity limits the detection to changes on the order of natural background levels or higher.

Small ion chambers (such as Victoreen Stray Radiation Chambers) with special readout can measure the small doses involved, but care should be taken to minimize leakage through the insulators. Thermoluminescent dosimeters (TLD's) are now being employed at some ties for measurement of environmental gamma doses. A recent development at Hanford has been an appropriate shield and methods for calibration and annealing, which together allow the use of TLD-200 (CaF_2:Dy) chips to measure doses as low as a few mR accumulated over a two or three week period.

The most widely used method for monitoring airborne radioactive materials is to draw an air sample through a filter at a fixed flow rate, and then periodically to collect the filter for laboratory analysis. The measurement of alpha activity on the filter is complicated by the fact that the atmosphere normally contains natural alpha activity in concentrations of the long-lived materials one might wish to measure. Fortunately, the natural alpha-emitting radionuclides in the atmosphere are short-lived and if one permits them to decay for six or eight hours, they will have decreased to a level which makes it possible to measure the presence of long-lived emitters.

A somewhat more reliable procedure is to count the filter at two different standardized times after collection, such as six hours, and forty-eight hours, and then to utilize a nomograph to correct for the short-lived radionuclides present on the filter.

Concentrations of naturally occuring beta emitters in the atmosphere are about the same order of magnitude as the alpha emitters. However the MPC's of most beta emitters are high enough so that significant increases above background can be detected. Here again, a short decay period after the initial collection will permit the natural radioactivity to decrease to negligible levels.

Several types of filter paper are available for air sampling. Plastic membrane filters have a high collection effeciency for submicron particles and will retain the collected dust near the surface where any alpha emitters present can be detected efficiently.

Airborne radioiodine can be sampled by drawing air through small charcoal cartridges. Both inorganic and organic forms of iodine will be collected efficiently if the temperature and humidity are not excessive, and if the face velocity of the air through the cartridge is kept below 200 feet/minute. Under more severe conditions of temperature and humidity charcoal impregnated with potassium iodide will exhibit satisfactory collection efficiency.

Air samplers may be equipped with devices for measuring and recording the activity collected on the filter. Stepwise or continuously moving strips of filter paper may also be used if a record of the air concentration vs. time is required. Suitable alarms can be added to indicate high radiation, loss of flow rate, etc.

Tritium oxide can be sampled by drawing air through cylinders containing silica gel. After use the sampler is returned to the lab where the collected moisure is removed by distillation and analyzed for tritium oxide content using a liquid scintillation counter. The sensitivity of such a system used at Savannah River Laboratory is 10 pCi/m^3, utilizing 3 ml of distillate, 21 ml of scintillation mixture and a 20 minute counting time. Before reuse the silica gel needs to be thoroughly dried to remove as much of the residual moisture (and tritium oxide) as possible, to limit cross contamination of samples.

Surface deposition can be monitored by repetitive instrument surveys or soil sampling at fixed locations around a facility. A more sensitive and reliable method is to periodically analyze deposition collection devices placed in the field. These can be glass wool paper, paper coated with a sticky surface, trays of water, or elaborate pots containing strips of paper designed to simulate grass.

Analysis of such collectors is often done by ashing at high temperature although volatile nuclides such as iodine and ruthenium will be lost in the process. Flat collectors can be covered with a thin layer of plastic and counted directly on a large area proportional counter. Grass is an excellent medium for trapping surface fallout and can be used as a sensitive indicator of deposition. It is particularly useful if a deposit of fresh fission products is suspected.

Food crops such as vegetables, cereal grain, meat, eggs, and milk can also contain radioactivity originating from atmospheric releases. In the vicinity of larger facilities where significant quantities of fission products, such as iodine, cesium and/or strontium, are released, milk should be sampled approximately every two weeks for analysis by gamma spectroscopy especially for radioiodine. Composite milk samples can be analyzed for longer-lived nuclides on a quarterly basis.

Other foods should be sampled at harvest time and analyzed by gamma spectroscopy and if necessary for ^{89}Sr and ^{90}Sr.

Bovine thyroids are a more sensitive indicator of the presence of radioiodine in the environs than are milk or vegetation. Arrangements can be made with a veterinarian to collect thyroid samples at a local slaughter house for shipment to the laboratory for analysis. Sampling of local meat and eggs should be done monthly to quarterly with analysis for gamma emitters and ^{89}Sr and ^{90}Sr.

b) <u>Monitoring related to releases to surface waters</u>

The release of radionuclides to streams, lakes, or oceans from a nuclear facility can also lead to radiation exposure through a variety of pathways. Figure 7 indicates the kinds of environmental measurements required to define the radiation doses to people in the environs. Drinking water, fish, waterfowl, and foods irrigated with contaminated water are the potential pathways leading to internal dose; fishing and hunting on the shoreline, boating, and swimming, and handling of contaminated fishing gear, are possible pathways leading to external exposure.

Samples of receiving waters are logically taken near the point of public use, i.e., where the recreation takes place, or where the water is withdrawn for drinking or for irrigation. If the effluent is so diluted by this time that accurate measurement of the concentrations is not possible, then sampling nearer the discharge point would provide better radiological control. Samples of a flowing stream taken upstream of the facility and far enough downstream for thorough mixing to have taken place, can be compared to estimate the radioactivity added to the stream.

Normally radionuclides of very short half-lives will not be of great concern and weekly samples of water should be sufficient. Determination of long-lived radionuclides can be made in samples continuously composited over periods of a week or a month. This is especially advantageous if the release rate is not uniform or if the river flow rate is variable. Measurements of gross beta activity may be sufficient when the concentrations are low ($\leq$ 10 pCi/ℓ) although the presence of natural uranium in some streams may dictate isotopic analyses at these levels.

Samples should be as representative of water actually consumed as possible. Municiple water plants which employ floculation and filtration steps will often remove a significant fraction of certain radionuclides. For example, experience with the water plants at Richland and Pasco, Washington, downstream of the Hanford project indicated the following removal efficiencies: 90% for ^{51}Cr; 80% for ^{131}I, 40% for ^{65}Zn, 30% for ^{64}Cu, and 20% for rare earths.

Direct measurements of radiation exposure over shoreline mud can be made with suitable portable instruments employing scintillation detectors or large volume ion chambers. Shoreline exposures and immersion dose rates in the water can be measured with dosimeters such as small ion chambers or TLD's left in position for one to four weeks in waterproof containers.

Samples of sediment upstream and downstream from the discharge point can be collected before and after the plant starts operating for laboratory analysis. Careful selection of sampling rates and proper interpretation of results is important. The quantity of radionculides present at a given time in a given shoreline location will be affected not only by the release rate, but also by the recent changes in stream velocity and elevation and season of the year (which will affect the types and amounts of organic debris available for deposition).

Fish and waterfowl can concentrate radionuclides through aquatic food chains. Even upland game birds and poultry living near the water can acquire radionuclides through ingestion of contaminated water and aquatic insects. Samples of fish and game birds should be harvested in season and at locations accessible to sportsmen. Poultry and eggs should be sampled monthly to quarterly throughout the year. Where effluents are discharged directly to the ocean or reach the ocean by way of the receiving stream, samples of seafood including shellfish should be collected. Monthly sampling of all of the above food is normally sufficient, since the concentration of radionuclides will change only slowly with time.

Pastures irrigated with contaminated water should be sampled about two to four times per year at times when the milk from the cows feeding on it is being sampled. Gamma spectrometeric analyses and radiochemical analyses for ^{89}Sr and ^{90}Sr should be performed on each sample.

Food crops should be sampled at harvest and analyzed for gross beta activity unless significant concentrations of radionuclides are present. In that case, gamma spectroscopy and analysis for ^{89}Sr and ^{90}Sr is required.

c) <u>Monitoring in relation to release to ground</u>

Liquid wastes may be released directly to the ground or may seep into the ground from open disposal ponds or trenches. Proper selection and management of the disposal site will eliminate most of the environmental problems. Radionuclides leaching from the disposal site into surface waters can be monitored by collecting samples of the latter waters. Where necessary ground water can be monitored through wells sunk around the periphery of the site. Nuclides which generally move freely with underground water flow include tritium oxide, ^{106}Ru and, in certain chemical complexes, ^{60}Co. Many soils have a capacity for retention of strontium and cesium (dependent to some extent on the pH and chemical composition of the waste solution) and these nuclides will not normally migrate a significant distance through the soils underlying the disposal site. However, tests of the behavior of radionuclides (from samples of the actual effluent) in the particular soil involved should be made prior to establishment of any disposal site discharging large quantities of radionuclides to the ground.

3) Emergency Surveys

These have to be carried out in situations where accidental releases of radioactive materials lead to significant contamination of the environs or high external exposure rates. They are generally designed to define the area and extent of the contamination spread.

Detection of an accident will normally depend upon the usual procedures for discerning abnormal conditions within the establishment and its environs. Should an emergency occur the immediate aim should be to bring it under control, and to reduce to a minimum injury to people and damage to property. For this reason each installation should promulgate, in detail, specific standing arrangements appropriate to all conceivable accidents for which it is reasonable to plan. Clear lines of responsibility should be defined for immediate control of an accident at its source and for initiating appropriate emergency action.

The emergency arrangements should provide for the most effective use of the resources available by providing for allocation of key personnel and facilities for emergency duty, and for the effective coordination of all the site services. They should also contain provision for assistance from outside the region affected. It is essential that emergency permissible levels should have been established.

The IAEA has published an excellent manual on environmental monitoring in emergencies which discusses in some detail rationale, procedures, potential accidents, and factors for converting field instrument readings to concentration levels in air, water, soil or vegetation.

Prompt action following the emergency would be essential to determine the extent of the contamination. In the case of a large release of airborne radioactivity containing gamma-emitting radionuclides, considerable time could be saved in determining the areas of serious contamination by conducting a rapid gamma survey using portable gamma monitors carried in light aircraft, helicopters, or automobiles. Car-borne and aerial survey equipment and techniques have been developed and tested in the United States, Canada, and the United Kingdom.

For the past 10 years a sophisticated aerial radiation detection and tracking system has been in operation to assist the U. S. Atomic Energy Commission in monitoring the impact of nuclear facilities on their environment. The system, referred to as ARMS (Aerial Radiological Measuring System), is an integral part of the USAEC environmental surveillance program.

The capability for rapid surveys with car-borne instruments has also been developed at the Japan Atomic Energy Research Institute's Tokai-Mura facility. Background surveys are performed about twice a year to provide information on levels of natural background radiation at pre-selected points.

The emergency environmental sampling program should include the collection of samples of airborne materials, drinking water and critical components in the food chain. Where air-monitoring networks exist around a facility, samples from the network may serve to evaluate radioactive concentrations in the cloud. Where no such networks exist, the collection of air samples may be futile unless the release continues over a relatively long period of time.

Samples of environmental media should be collected throughout the area of contamination to define its boundaries and evaluate the hazard to the neighboring population. The number and types of samples will depend on the utilization of the affected area (i.e., whether or not food such as milk, vegetables, eggs and beef is produced). The numbers of samples and schedule for resampling will be governed by the duration of the radioactive release and the persistence of significant levels of contamination in the environs.

Analyses of samples for gross radioactivity will help to define the extent of the contaminated area and to establish general levels of contamination. Analyses for specific radionuclides are necessary, however, to evaluate the extent of economic damage to property and the hazard to man and to make intelligent decisions with regard to the action required in coping with the emergency.

F) Typical Surveillance Programs

A typical program is summarized in Table 4.

G) Manpower and Laboratory Requirements

The operation of a surveillance program embraces a number of activities from designing the survey, directing the survey, collecting samples, and analyzing samples, to interpreting the data obtained. Professional advice from many sources may be required during the planning phase and at least one professionally trained scientist is needed to supervise the program initially. The scientist in charge of the survey should have an understanding of, and access to advisors in, sampling techniques, operation and maintenance of counting equipment, chemical analyses, statistical evaluation of data, and general health physics.

The number of supporting technical staff needed will depend a great deal upon the magnitude and scope of the survey. It is generally found that someone with the equivalent of a high school education can carry out the routine procedures used in environmental survey work. Training is essential, however, if samples from the field are to be properly collected and analyzed according to specialized procedures.

The equipment and laboratory facilities required vary according to the scope of the survey. The measurement of gross activity requires the usual facilities of a small chemical laboratory supplemented by relatively simple counting devices. Analysis for specific nuclides will normally not require other than conventional laboratory equipment, but it is expensive in time. Further, the sensitivity of the counting equipment generally needs to be greater than if, for example, only gross beta activity is measured. Time may be saved by making use, when possible, of gamma-ray spectrometry.

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TABLE 4

Typical Environmental Surveillance Program for a Nuclear Power Plant

	Recommended Surveillance Program		
Vectors or Indices	Relative Frequency	Analyses	Sampling Locations
Surface Water Receiving waters of the facility	Continuous composite or weekly grab	Gross beta and gamma scans. Periodic analysis for H, U and Pu with frequency a function of the levels measured.	Stream--above and below the facility; reservoir, bay, lake--nearest shoreline; any nearby domestic water suppliers using the receiving waters as a raw water source.
Bottom Sediments	Semiannually	Gross beta and gamma scans. Periodic analysis for H, U, and Pu with frequency a function of the levels measured.	Near reactor's outfall or above and below the outfall if the receiving water is a stream.
Ground Water	As applicable (usually quarterly or annually)	Gross beta and gamma scans.	Supplies within 5 miles of the facility.
Air: a) Inhalation	High-volume samples occasionally Low-volume samples daily or weekly	Gross beta and gamma scans of filters and cartridges.	Populated areas within 5-15 miles of the facility.
b) Immersion	Dosimeters changed monthly	Integrated dose due to noble gases by appropriate reader advice.	
Milk	Monthly	Gamma spectrum analysis for ^{131}I	Dairy herds within 10-15 miles of the facility.
	Quarterly	^{89}Sr and ^{90}Sr or total Sr by beta analysis	Dairy herds within 10-15 miles of the facility.

TABLE 4 (CONT'D)

Vectors or Indices	Relative Frequency	Analyses	Sampling Locations
Aquatic biota	Variable	Gamma spectrum analysis for selected radionuclides	Near the reactor's outfall or above and below if receiving water is a stream.
Food crops and other vegetation	Seasonal (before or at harvesting time)	Gamma spectrum analysis	Within a 10-15 mile radius of the facility.
Soil	Annually	^{90}Sr and ^{137}Cs or gross beta	Prevailing downwind direction in nearest agricultural areas.

BIBLIOGRAPHY ON ENVIRONMENTAL SURVEILLANCE

1) Environmental Contamination by Radioactive Materials, Proceedings of a Seminar held in Vienna, March 24-28, 1969, International Atomic Energy Agency, Vienna, 1969.

2) Environmental Surveillance in the Vicinity of Nuclear Facilities (W. C. Reinig, Ed.), Proceedings of a Symposium held at Augusta, Ga., Jan. 24-26, 1968, Charles C. Thomas, Publisher; Springfield, Ill., 1970.

3) P. G. Voillequé and B. R. Baldwin (Compilers), Health Physics Aspects of Nuclear Facility Siting, Volumes I, II and III, Proceedings of a Symposium held at Idaho Falls, Idaho; Nov. 3-6, 1970, Health Physics Society, Eastern Idaho Chapter, P. O. Box 2431, Idaho Falls, Idaho, 1971.

4) Environmental Aspects of Nuclear Power Stations, Proceedings of a Symposium held at New York, August 10-14, 1970, International Atomic Energy Agency, Vienna, 1971.

5) Radioactive Materials in Food and Agriculture, FAO Report No. 2, Food and Agriculture Organization of the U. N., Rome, 1960.

6) Organization of Surveys for Radionuclides in Food and Agriculture, Report of an FAO Expert Committee, FAO Atomic Energy Series No. 4, Food and Agricultural Organization of the U. N., Rome, 1962.

7) Methods of Radiochemical Analysis, World Health Organization, Geneva, 1966.

8) Routine Surveillance for Radionuclides in Air and Water, World Health Organization, Geneva, 1968.

9) Manual on Environmental Monitoring in Normal Operation, IAEA Safety Series No. 16, International Atomic Energy Agency, Vienna, 1966.

10) Environmental Monitoring in Emergency Situations, IAEA Safety Series No. 18, International Atomic Energy Agency, Vienna, 1966.

11) M. Eisenbud, Environmental Radioactivity, McGraw Hill Book Company, Inc., New York, 1963.

12) R. E. Allen (Compiler), Radiation Surveillance Networks, USAEC Report WASH-1148, Division of Operational Safety, U. S. Atomic Energy Commission, Wash., D. C., 1969.

13) J. A. Lieberman, E. D. Harward, C. L. Weaver, "Environmental Surveillance Around Nuclear Power Reactors," Radiological Health Data & Reports, 11:325-332 (1970).

14) J. F. Honstead, "Bases for Environmental Survey Design," pp. 40-45 in Environmental Surveillance in the Vicinity of Nuclear Facilities (W. C. Reinig, Ed.), Proceedings of a Symposium held at Augusta, Ga., Jan. 24-26, 1968, Charles C. Thomas Publishers; Springfield, Ill., 1970.

15) J. F. Honstead, "A survey of Environmental Dose Evaluations," Nuclear Safety 9 (No. 5): 383-393 (1968).

16) J. P. Corley, "Hanford Experience with Composite Environmental Dose Estimates," pp. 191-198 in Environmental Surveillance in the Vicinity of Nuclear Facilities (W. C. Reinig, Ed.), Proceedings of a Symposium held at Augusta, Ga., Jan. 24-26, 1968, Charles C. Thomas, Publisher, Springfield, Ill., 1970.

17) Recommendations of the International Commission on Radiological Protection, Report of Committee II on Permissible Dose for Internal Radiationn 1959, ICRP Publication 2, Pergamon Press, New York, 1960.

18) Principles of Environmental Monitoring Related to the Handling of Radioactive Materials, A Report by Committee 4 of the International Commission on Radiological Protection, ICRP Publication 7, Pergamon Press, New York, 1966.

19) J. F. Honstead, "Quantitative Evaluation of Environmental factors affecting Population exposure Near Hanford," pp. 266-277 in Health Physics Aspects of Nuclear Facility Siting (Compiled by P. G. Voillequé and B. R. Baldwin), Proceedings of a Symposium held at Idaho Falls, No. 3-6, 1970, Eastern Idaho Chapter, Health Physics Society, P. O. Box 2431,

20) A Preston and D. F. Jefferies, "The ICRP Critical Group Concept in Relation to the Windscale Sea Discharges," Health Physics 16:33-46 (1969).

21) H. J. Dunster, A. W. Kenny, W. T. L. Neal and A. Preston, "The British Approach to Environmental Monitoring," Nuclear Safety 10 (no. 6) 504-513 (1969).

22) E. G. Struxness, et. al., Comprehensive Report of the Clinch River Study, USAEC Report ORNL-4035, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1967.

23) J. K. Soldat, Environmental Monitoring Lecture Notes, USAEC Report BNSA-125, Pacific Northwest Laboratory, Richland, Wash., 1965.

24) H. H. Abee, "Environmental Surveys Following Accidental Release," Nuclear Safety 6 (No. 1):87-89 and 95-96 (1954).

25) Z. G. Burson, J. F. Doyle, A. E. Fritzsche, "Aerial Radiological surveying of Nuclear Facilities - Status Through 1970,) American Nuclear Society Transactions 14 (No. 1):65-66 (1971).

26) Environmental Monitoring at JAERI Tokai in 1969, JAERI-Memo 4175, Japan Atomic Energy Research Institute, Tokai Research Establishment, Tokai Research Establishment, Tokai-Mura, Japan, 1970.

27) W. C. Roesch, R. C. McCall and F. L. Rising, "A Pulse Reading Method for Condensor Ion Chambers," Health Physics 1:340-344 (1958).

28) W. L. Marter and C. M. Patterson, "Monitoring of Tritium in Gases, Liquids and in the Environment," American Nuclear Society Transactions 14 (No. 1): 162-163 (1971).

29) J. K. Soldat, "The Relationship Between ^{131}I Concentrations in Various Environmental Media," Health Physics 9:1167-1171 (1963).

30) E. C. Tsivoglou, "Environmental Monitoring Around a Uranium Mill in the USA," pp. 63-70 in Manual on Environmental Monitoring in Normal Operation, IAEA Safety Series No. 16, International Atomic Energy Agency, Vienna, 1966.

31) E. T. Wray (Ed.), Environmental Monitoring Associated with Discharges of Radioactive Waste During 1969 from USAE Establishments, UKAEA Report AHSB (RP)R 105, United Kingdom Atomic Energy Authority, Health and Safety Branch, Harwell, Berkshire, 1970.

32) C. L. Weaver, E. D. Harward, "Surveillance of Nuclear Power Reactors," Public Health Reports, 82-899-912 (1967).

33) W. L. Brinck, E. D. Harward, R. I. Chissler, "Programs for Environmental Surveillance Around Nuclear Power Plants," pp. 46-54 in Environmental Surveillance in the Vicinity of Nuclear Facilities (W. C. Reinig, Ed.) Proceedings of a Symposium held at Augusta, Ga., Jan. 24-26, 1968, Charles C. Thomas Publisher; Springfield, Ill., 1970.

34) B. Kahn, R. L. Blanchard, H. L. Krieger, H. E. Kolde, D. B. Smith, A. Martin, S. Gold, W. J. Averett, W. L. Brinck, and G. J. Karches, "Radiological Surveillance Studies at a Boiling Water Nuclear Power Reactor," pp. 535-548 in Environmental Aspects of Nuclear Power Stations, Proceedings of a Symposium held at New York, Aug. 10-14, 1970, International Atomic Energy Agency, Vienna, 1971.

35) L. Lewis, "Environmental Monitoring for Nuclear Power Plants - A Utility Health Physicist's Viewpoint," paper presented at Southeastern Electric Exchange, Engineering and Operation Division Conference, Atlanta, Ga., Oct. 21-22, 1968, Duke Power Company, Charlotte, N.C., 1968.

36) B. W. Clark, "Description of the Environmental Monitoring Program for the Monticello Nuclear Generating Plant near Monticello, Minn., Revised June 1, 1969," Northern States Power Company, Minneapolis, Minn., 1969.

37) L. C. Oyen, "Development of the Quad-Cities Nuclear Power Station Environs-Monitoring Program," paper presented at the ASME Winter Meeting, Nov. 16-20, 1969, Los Angeles, California, The American Society of Mechanical Engineers, United Engineering Center, 345 East 47th St., New York, 1969.

38) M. E. Miles, J. J. Mangeno and R. D. Burke, "Environmental Monitoring and Disposal of Radioactive Wastes from U. S. Naval Nuclear-Powered Ships and Their Support Facilities, 1970", Radiological Health Data and Reports 12:235-244 (1971).

39) Staff, Division of Environmental Health Services, "Western N. Y. Nuclear Service Center, Preoperational Environmental Study--Preliminary Report," N. Y. State Health Dept., 1962.

40) Staff, Division of Environmental Health Services, "Western N. Y. Nuclear Services Center, Preoperational Environmental Survey," N. Y. State Health Dept., 1964.

41) B. Shleien, An Estimate of Radiation Doses Received by Individuals Living in the Vicinity of a Nuclear Fuel Reprocessing Plant in 1968, USPHS Report BRH/NERHL 70-1, U. S. Public Health Service, Northeastern Radiological Health Lab., Winchester, Mass., 1970.

42) H. J. Dunster, "Environmental Monitoring: British Policy and Procedures," pp. 427-437 in Environmental Aspects of Nuclear Power Stations, Proceedings of a Symposium at New York, August 10-14, 1970, International Atomic Energy Agency, Vienna 1971.

43) P. E. Bramson and J. P. Corley, Surveillance at Hanford for CY-1971, USAEC Reports BNWL-1683, Pacific Northwest Laboratory, Richland, Wash., 1972.